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15. SUPPLEMENTARY NOTES This is a companion document to Air Force Logistics Command Guidelines for Exchangeable APT Data Packages, Final Report <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.					
16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) A method of APT programming and postprocessor design has been developed which permits more efficient data preparation for numerical control (NC) machine tools and then allows this data to be quickly and easily exchanged among different NC machines. This is accomplished through rigorous specification of the APT postprocessor language based upon new ANSI standards for APT plus a comprehensive definition of the machining functions which should result from the use of each APT language statement. Individual postprocessors are modified to process each statement in the same manner. This document sets forth minimum specifications for the procurement of APT Postprocessors consistent with the standardized postprocessing language concept. It is expected that these specifications will be used in future machine tool procurements. The concept was successfully demonstrated in production by processing a single APT data package on three different milling-drilling type machine tools. A 23% increase in NC manufacturing efficiency is projected.					
17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons) APT; Automation; Computer aided manufacturing; NC machining; NC programming; Numerical Control; Part programming, Software specifications					
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GUIDELINES FOR EXCHANGEABLE APT DATA PACKAGES

APT Postprocessor Specifications

Bradford M. Smith

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PREFACE

This report documents work done at the National Bureau of Standards for the Air Force Logistics Command under Military Interdepartmental Purchase Request FD 2040 78 60013 from the Producibility, Reliability, Attainability and Maintenance Office at Sacramento Air Logistics Center. The Project Manager at Sacramento was Mr. Cleon Binyon, and software modifications were under the direction of Mr. Malcolm Allen at Ogden Air Logistics Center.

INTRODUCTION

This document sets forth minimum specifications for the procurement of APT Postprocessors for numerical controlled (NC) machine tools in the Air Force Logistics Command (AFLC). The objective is to obtain software which maximizes the productivity of the NC equipment within the AFLC environment. This involves providing the ability to quickly and easily exchange part programs among different NC machine tools. Such portability of APT part program data is achieved through a careful standardization of postprocessor language syntax and semantics, based upon ANSI X3.37-1980, with the burden being placed on the postprocessor to satisfy the intent of the part programmer at all times. It is the purpose of this specification to provide software which functions correctly, which fully exercises all machine tool capabilities, and which is well documented. To this end, these specifications will address the following topics:

1. SYSTEM REQUIREMENTS

The computer system interface requirements for postprocessor operation. The coding and blocking of the output punch file which subsequently is used to generate the NC machine control media.

2. FUNCTIONAL REQUIREMENTS

The syntax of APT postprocessor language to be used and the semantics, the desired functions to be performed at the NC machine tool for each postprocessor language statement. Error conditions to be detected by the postprocessor and highlighted on the output listing.

3. DOCUMENTATION REQUIREMENTS

Documentation for computer programmer and part programmer. Instructions for manual programming and for postprocessor implementation.

4. POSTPROCESSOR PROGRAM TAPE

The form in which the software shall be delivered to the using activity.

5. SOFTWARE VALIDATION

The methods by which the postprocessor is to be tested for conformance with this specification.

6. POSTPROCESSOR MACHINING TEST

The methods by which the postprocessor output tape is to be tested for properly exercising machine tool functions.

TABLE 1

MAJOR and MINOR WORD INTEGER CODES

MAJOR WORDS		MINOR WORDS	
AIR	1011	ALL	51
BREAK	16	ATANGL	1
CLAMP	1060 ~	AUTO	88
CLRSRF	1057	BORE	82
COOLNT	1030	BOTH	83
CUTCOM	1007	CCLW	59
CYCLE	1054	CIRCUL	75
DELAY	1010	CLW	60
END	1	CSINK	256
FEDRAT	1009	DEEP	153
GOHOME	14 ~	DIAMTR	205
INSERT	1046	DRAG	278
LEADER	1013	DRILL	163
LINTOL	1068 ~	DWELL	1058
LOAD	1075	FACE	81
MACHIN	1015	FEDTO	281
MCHTOL	1016	FLOOD	89
OPSKIP	1012	FRONT	148 *
OPSTOP	3	HEAD	1002
ORIGIN	1024 ~	HIGH	62
PARTNO	1045	HOMEPT	154 *
PIVOTZ	1017	INCR	66
PPRINT	1044	IPM	73
RAPID	5	IPR	74
RETRCT	7	KEYLCK	282 *
REWIND	1006	LEFT	8
ROTATE	1066	LINEAR	76
SELECT	1074 #	LOCK	114
SEQNO	1019	LOW	63
SET	1087	MAIN	93 ~
SPINDL	1031	MANOP	248 ~
STOP	2	MANUAL	158
TMARK	1005	MAXRPM	79
TRANS	1037	MEDIUM	61
		MILL	151
		MIST	90
		MODE	1003
		NEUTRL	302 ~
		NODRAG	278 ~
		OFF	72
		OMIT	172 *
		ON	71
		OPTION	144
		PARAB	77
		RADIUS	23
		RAIL	93
		RANGE	145
		RAPFED	127 *
		RAPOUT	189 #
		RAPTO	280 ~
		REAM	167 ~
		REAR	149 *
		REV	97
		RIGHT	24
		ROTREF	68
		RPM	78
		SADDLE	150
		SIDE	94
		SFM	115
		STEP	92 ~
		TABLE	177
		TAP	168
		TAPKUL	91 *
		TLANGL	156 ~
		TLCHG	147 *
		TLSET	155 #
		TOOL	240 #
		XAXIS	84
		XYPLAN	33
		YAXIS	85
		YZPLAN	37
		ZAXIS	86
		ZXPLAN	41

NOTES:

- * Extension to ANSI X3.37-1980 Standard APT vocabulary
- ~ Integer Code differs with ANSI X3.37-1980
- # Integer Code not assigned by ANSI X3.37-1980

SYSTEM REQUIREMENTS

The APT system and its postprocessors are resident on an IBM 360/65 computer operating under OS/MVT release 21.8F with RJE/HASP version 3.2. The part programs are input to the IBM 360 thru a Systems Engineering Laboratories Model 32/55 computer which emulates a standard IBM HASP interleaving work station.

The postprocessor shall be compatible with the IBM System/360 APT Numerical Control Processor (360-CN-10X) Version 4, Mod 3. This general processor is used by all AFLC installations for generating Numerical Control Part Programs.

The postprocessor load module shall execute in a region size not to exceed 256 K bytes. This 256 K includes a 48 K APT processor control region leaving a net postprocessor region size of 208 K bytes. Overlays are acceptable.

Input to the APT Postprocessor shall be tool position data on the APT Center Line (CL) file. Format and structure of this file are given in the System/360 APT Numerical Control Processor Operations Manual. Integer coding of APT postprocessor major and minor words shall conform to Table 1.

The FORTRAN language shall be used to the maximum extent possible. The compiler used by AFLC is IBM 360 FORTRAN IV Level H. Programming techniques which exploit undefined or non-standard features of FORTRAN, or exploit unique features of a particular compiler are not acceptable.

No modification of the APT processor may be made by the postprocessor during its execution. The postprocessor writer is encouraged to use the APT general processor utility routines for performing system functions such as reading CL records. Use of these routines shall be documented as external requirements in the Computer Programmer's Guide.

The machine control tape shall be output from the postprocessor as an 80 character card image NC Output file with card columns 1 thru 72 containing machine tool coding and columns 73 thru 80 containing an optional card sequence number.

NOTE: Certain commercial equipment is identified in this report to adequately specify the software procedure. In no case does this identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the equipment is necessarily the best available for the purpose.

Starting information on the NC Output file, triggered by the PARTNO statement, shall be the contents of the PARTNO statement in man-readable form followed by 24 to 36 inches of leader. The punch codes comprising the man-readable section shall not use channel 8 of the tape.

Final information on the NC Output file, triggered by the FINI statement, shall be a Rewind command (M30) plus an End of Block command followed by 24 to 36 inches of leader.

The End of Block Character (EOB) output by the postprocessor shall be a dollar sign (\$) or hollerith 11-3-8 punch. The End of Record (EOR), tape mark (TM), and Rewind Stop (RS) code characters shall be a pound sign (#) or hollerith 3-8 punch.

The text output of the postprocessor shall be in a format for printing on 132 column paper (11 x 14-7/8 inches). Each page of the listing shall contain a heading consisting of the contents of the PARTNO statement, the machine tool name, the postprocessor name and a consecutive page number.

Each control block generated by the postprocessor shall be printed on a separate line of the text output listing. Information shall include:

- Section 1 statement number
- Section 3 CLDATA record number
- Control tape block number
- End of motion machine coordinates
- Feedrate in IPM/CSS
- Spindle speed in RPM/CSS
- Elapsed machine run and dwell times
- Accumulated control tape footage

The diagnostic comments on the text output shall contain a meaningful description of the errors involved. The total number of errors and warnings shall be printed at the end of the postprocessor listing.

FUNCTIONAL REQUIREMENTS

The purpose of an APT postprocessor is to interpret the tool position data from the APT general processor and to direct the operation of the selected NC machine tool. Tool position data resulting from an APT part program is expressed on the Center Line (CL) file containing cutter path, feedrate along that path and auxiliary commands to be executed at certain positions. The CL data represents the part programmer's intent for the machining operation. Each APT postprocessor shall satisfy this intent at all times. Elements of this task are:

Every legal APT CL record shall be acceptable to the postprocessor without fatal error. Detailed syntax of these records is to be found in American National Standards Institute document X 3.37 - 1980 on APT.

The postprocessor shall insure that CL records produce the functional response at the machine tool as specified in the AFLC APT Part Programmer's Manual.

Where the required operations cannot be accomplished by exercising automatic functions of the machine or the controller, the postprocessor shall accomplish the operation by alternative means, calling for operator assistance if necessary.

Any deviation from the functions in the AFLC Part Programmer's Manual and any language extensions shall be thoroughly documented in the Part Programmer's Guide supplied with the postprocessor.

The postprocessor may ignore any legal APT CL record if a warning diagnostic is issued on the printed output and if such handling is described in both the Part Programmer's and the Computer Programmer's Guides.

APT CL records which appear to be illegal or undefined shall be flagged with a diagnostic message indicating the source statement at fault.

The postprocessor shall guard against any commands that would cause damage to the cutter, machine, or workpiece.

The postprocessor shall recognize commands which exceed the limitations of machine or controller and, if possible, output suitable action. If not possible, the postprocessor shall issue diagnostic messages to the programmer identifying the source statement at fault.

The postprocessor shall provide for adequate validation of input data and for orderly recovery when an unknown or undefined combination of input parameters occurs.

DOCUMENTATION REQUIREMENTS

Text and graphic documentation shall be provided to fully describe the implementation, operation, use and maintenance of the postprocessor software over the life of the machine tool. Four particular forms of documentation are required; a Computer Programmer's Guide, a Part Programmer's Guide, a Guide for Manual Programming and an Implementer's Guide. Three copies of the documentation shall be furnished and delivered concurrently with the postprocessor.

Computer Programmer's Guide

The Computer Programmer's Guide shall describe the operation, modification and maintenance of the software. It shall contain as a minimum the following information:

- Narrative of the general organization of the postprocessor.

- Narrative of the purpose and general flow of each subroutine including the purpose and coding of all arguments.

- The purpose, content and function of any overlays.

- The function and usage of all data arrays including the operation and coding of all intermediate data buffers.

- Identification of all error diagnostic messages and their originating subroutine.

- The function and possible states of each flag variable including references to where it is set and where it is used.

- Identification of machine tool and controller constants used by the program. Explain the use of each parameter and the method by which its value is calculated. Indicate how they may be changed and what portions of the program are affected by a change.

- The assignment of COMMON variable blocks and the definition and use of each variable name within the COMMON area.

- Examples of all built in debugging aids used to localize software problems.

- Description of methods used to compute functions such as:

 - Acceleration-Deceleration
 - Tool axis orientation
 - Coordinate system transformations
 - Coded feedrate numbers
 - Coded spindle speeds

Part Programmer's Guide

The Part Programmer's Guide shall describe all special rules which shall be followed by a part programmer in using the post-processor. The guide shall act as a supplement to the AFLC APT Part Programmer's Manual in specifying additional information as identified below:

Examples of common programming practice and interpretation of typical output listings.

Usage of all machine dependent APT language commands such as MACHIN, ORIGIN and INSERT.

Illustrations of the physical axes of the machine tool including maximum departures and collision avoidance zones.

Listings of all part programmer error diagnostics and their probable cause.

Descriptions of all default values assumed by the postprocessor.

Limitations and restrictions on part programming techniques or on input data values.

Usage of any APT language extensions not elsewhere documented, particularly those which are unusual or differ from ANSI Standard, APT Encyclopedia or APT Dictionary usage.

Identification of applicable reference documents such as the Manufacturer's machine tool description and the control system description.

Guide for Manual Programming

The Manual Programmer's Guide shall describe all information necessary to code the NC tape manually. It shall contain as a minimum a description of the following:

tape format and coding

preparatory and auxiliary functions

critical machine limits

coding procedure and precedence

data calculations

Implementer's Guide

The Implementer's Guide shall describe all information necessary to implement the postprocessor. It shall contain as a minimum the following information:

Narrative of the implementation on the target APT system.

Installation steps including the job control language necessary to execute each step.

Execution procedures including the necessary job control language.

Unique design characteristics of the postprocessor.

Procedures for modifying or changing postprocessor routines.

POSTPROCESSOR PROGRAM TAPE

The postprocessor shall be delivered on a magnetic tape with the following physical characteristics:

9 Track
Non-labeled.
800 BPI.
Blocked 80 X 800.

As a minimum the postprocessor tape shall contain two files:

Postprocessor Source Code.

APT Test Part Program.

This program shall include coding designed to exercise the postprocessor's ability to call all postprocessor subroutines, and to generate the NC output data necessary to adequately test the machine's capability to perform the general operating characteristics, auxiliary functions, and miscellaneous functions specified in the purchase description as well as the functions associated with any attachments or accessories.

SOFTWARE VALIDATION

The postprocessor program tape and the postprocessor documentation described above shall be furnished to the using activity who will in turn forward the package to Hill Air Force Base for computer and compiler compatibility testing.

Hill AFB will refer to the Postprocessor Implementer's Guide to compile the Postprocessor Source Code. Of specific interest will be the compatibility of the postprocessor with the user's computer system specified herein. The source program shall be able to be read from the Postprocessor Program Tape and be successfully compiled without generating errors or causing system failure.

Hill AFB will compile the APT Test Part Program included on the program tape and use the CL data generated to test the capability of the postprocessor to successfully produce a text listing and NC output tape without causing system failure or generating unresolvable diagnostics. Both the listing and the NC output tape generated shall conform to the specifications herein.

If the Software Validation Tests are successful, Hill AFB will forward the program tape to the using activity for use in the Postprocessor Machining Test. All postprocessor errors or system failures will be reported to the manufacturer and shall be corrected by the manufacturer before the Postprocessor Machining Test.

POSTPROCESSOR MACHINING TEST

A machining test using the NC output tape defined in the Software Validation section shall be demonstrated on the NC machine after its installation at the using activity. The test shall demonstrate the ability of the NC system and machine to perform the machining operations required herein. The NC output tape together with the part produced by the tape shall form a component of the final acceptance of the postprocessor and the machine tool. The material for the test part and the type of tooling used may be of the supplier's choice. The spindle speeds and the feedrates used shall be based on optimum cutting conditions. All tools and materials required for the test shall be furnished by the manufacturer.

REFERENCES

The following references may be used for additional information.

1. System/360 APT Numerical Control Processor Systems Manual
GY20-0080-2.
2. System/360 APT Numerical Control Processor Operations Manual
GH20-0331-6.
3. Guidelines for Exchangeable APT Data Packages
Final Report - NBS Report NBSIR 80-2073.1
4. Guidelines for Exchangeable APT Data Packages
Part Programmer's Manual - NBS Report NBSIR 80-2073.2